

Recent Results from the Mars Global Surveyor Ka-Band Link Experiment (MGS/KaBLE-II)

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MGS Ka-Band Link Experiment

- The Mars Global Surveyor (MGS) Spacecraft Carries an Experimental Ka-band (32 GHz) Telecommunications Link in addition to the primary X-band (8.4 GHz) downlink
- The Ka/X Signals are simultaneously transmitted from a 1.5-meter High-Gain Antenna (HGA) on MGS and are received by a 34-meter beam-waveguide antenna (BWG) located in NASA's Goldstone DSN complex
- The KaBLE-II Experiment allows the performances of the two signals to be compared under nearly identical conditions
- The two signals have been regularly tracked since December 1996
 - Carrier signal level data (P_c/N_0)
 - Frequency and phase data
 - Ranging Demonstration
 - Telemetry Demonstration
- Measurements confirm that Ka-band could increase data capacity by at least a factor of three (5 dB) compared to X-band
 - Reduce cost, power, mass, and volume of future space missions

MGS/KaBLE-II Spacecraft Configuration

- MGS was conceived as a low cost rapid replacement for Mars Observer (MO)
- MO carried KaBLE-I
 - KaBLE-I functioned well and produced reasonable results during cruise
 - Had limitations
 - Ka-band frequency (33.7 GHz) was outside of deep space allocation band
 - Ka-band used back side of subreflector as antenna instead of main HGA surface
 - Ka-band used lower transmitter power
- MGS has increased Ka-band EIRP
 - Uses HGA instead of backside of subreflector
 - 1.2 W transmitted power instead of 25 mW
- MGS transmits within DSN allocation band
 - frequency within 31.8-32.2 GHz, instead of at 33.7 GHz

MGS/KaBLE-II Spacecraft Configuration

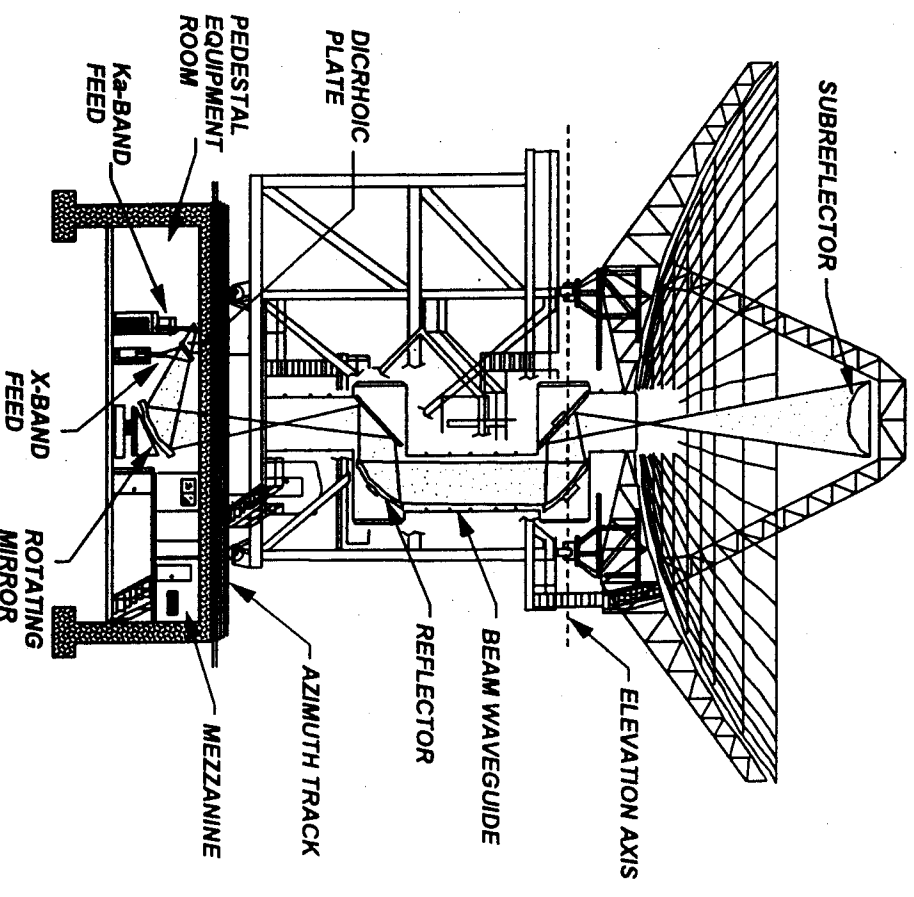
- MGS was conceived as a low cost rapid replacement for Mars Observer (MO)
- MO carried KaBLE-I
 - KaBLE-I functioned well and produced reasonable results during cruise within its design limitations:
 - Frequency (33.7 GHz) was outside of deep space allocation band
 - Antenna diameter was 27cm, 37 db gain (used back side of subreflector instead of main 1.5 m diameter main reflector surface); x-band antenna gain was 40 dB
 - Transmit power was only 25 milliwatts, derived from a varactor diode x4 multiplier driven by 0.8 Watts coupled from the X-band downlink
 - Ka-band EIRP was 50 dBm (vs 83 dbm at X-band)
- MGS has increased Ka-band EIRP and is in the DSN allocated frequency band
 - Uses HGA 1.5 m diameter main reflector for both Ka- and X-band simultaneously. Ka-band gain 46 dB; X-band gain 39 dB
 - Transmit power 1 W
 - EIRP = 76 dBm (26 dB increase over MO/KaBLE-I)
 - Frequency is within 31.8-32.2 GHz DSN allocation band

MGS/KaBLE-II Ground Station Configuration

- DSS-13 is a 34-meter beam-waveguide (BWG) antenna
 - Main reflector and subreflector
 - X-band Efficiency is about 71%
 - Ka-band Efficiency varies from 30% to 57% depending on elevation angle
 - BWG mirrors guide and focus energy to subterranean pedestal room
 - Dichroic plate allows for simultaneous reception of X-band and Ka-band signals
 - Feedhorns receive energy and guide it to Low Noise Amplifiers
 - 25 dBi X-band feedhorn
 - 26 dBi Ka-band feedhorn - monopulse receiver feed package
 - Follow-on equipment downconverts RF to 300 MHz IF and fiber optics/cables guide IF signals to control room receivers
 - Experimental Tone Tracker
 - Monopulse Receiver
 - Total Power Radiometer
 - Telemetry Processor Receivers
 - Ancillary data recorded
 - Surface Meteorological Data (Pressure, air temperature, relative humidity, wind speed, etc.)
 - Water Vapor Radiometer (includes sky brightness temperatures at 31.4 GHz)

DSS 13 R&D Beam Waveguide (BWG) Antenna

- R&D 34-m BWG antenna was built as a prototype for the evolving DSN BWG subnet
- Provides stable environment for feed, receiver and electronics development
- Provides easy access to multiple development stations at feed ring located in subterranean pedestal room
- Lower maintenance costs compared to non-BWG antennas
- Less susceptible to weather, for example, lower attenuation during rain



MGS/KaBLE-II Results

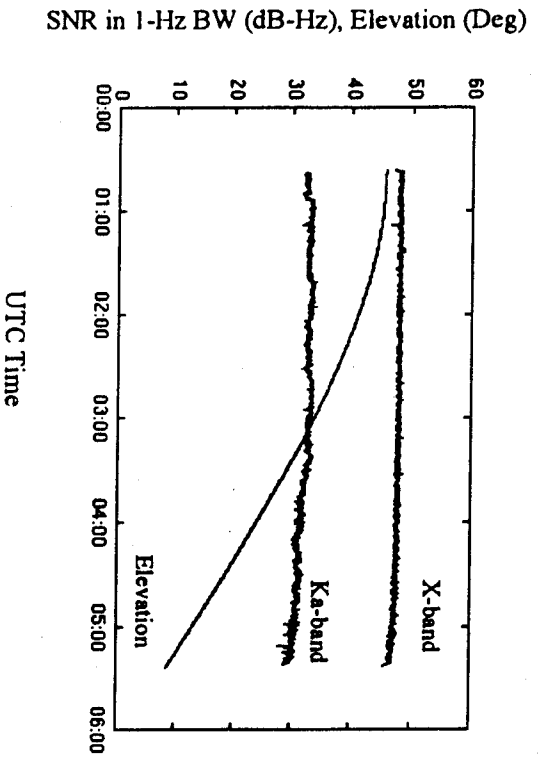
Signal Strength Data (P_c/N_o)

ETT Residual Carrier Tracking

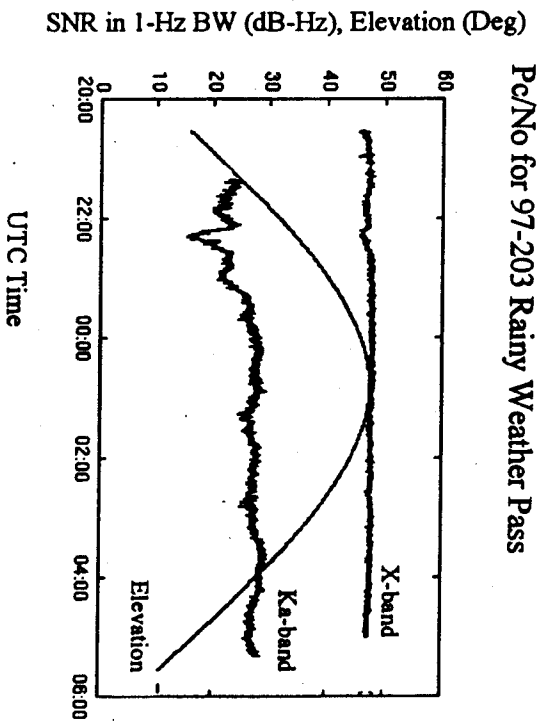
- 183 passes were conducted between December 1996 and September 1998
- For 169 passes, a Ka-band signal was detected, locked onto and recorded for a significant duration of each track
 - The received signal strengths varied due to spacecraft range, spacecraft mis-pointing, modulation index, ranging modulation, ground station configuration, weather attenuation, ground station mis-pointing, spacecraft temperature and downlink frequency.
- For 117 passes, prime dual-band signal level data were acquired with the spacecraft configured on the HGA and with ground station pointing control
 - The atmospheric attenuation averaged over a pass varied from 0.1 to 0.9 dB.
 - Spacecraft mis-pointing translated to up to 2 dB variations in measured signal level at Ka-band
 - Data acquired with a 61.5 deg telemetry modulation index, 21.3 kHz subcarrier
 - Most of these data were acquired during cruise prior to Mars Orbit Insertion
 - Some data acquired during May 1998 Solar Corona Experiment
 - Data acquired with a 80 deg telemetry modulation index, 320 kHz subcarrier
 - Most of these data were acquired since Mars Orbit Insertion

Examples of Pc/No Signal Level and Noise Temperature Data

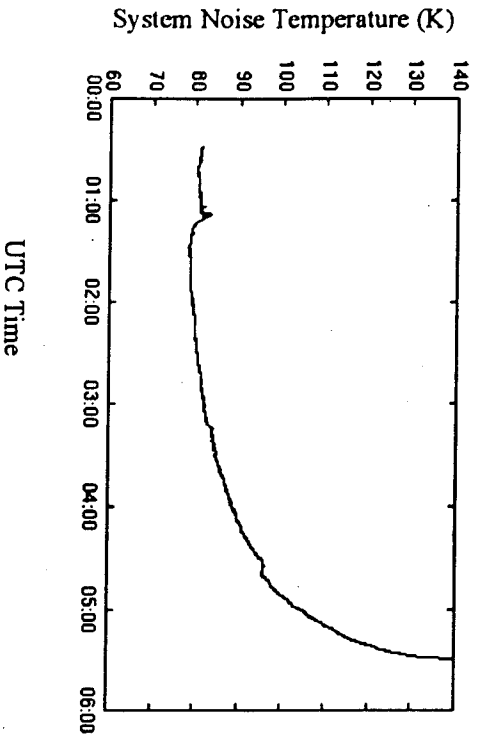
Pc/No for 97-212 Nominal Weather Pass



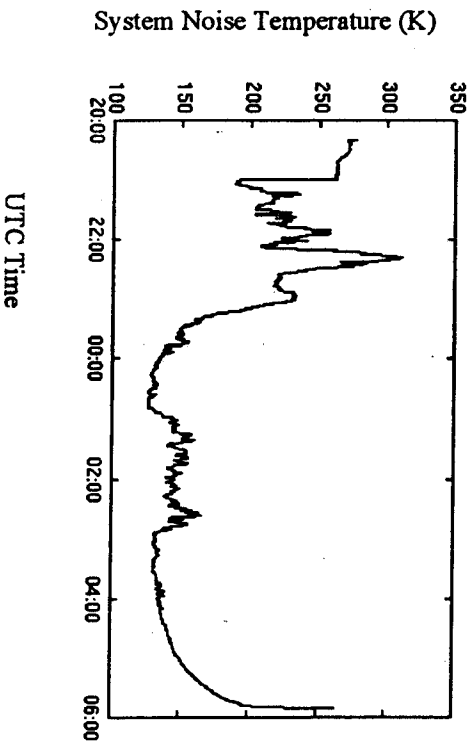
Pc/No for 97-203 Rainy Weather Pass



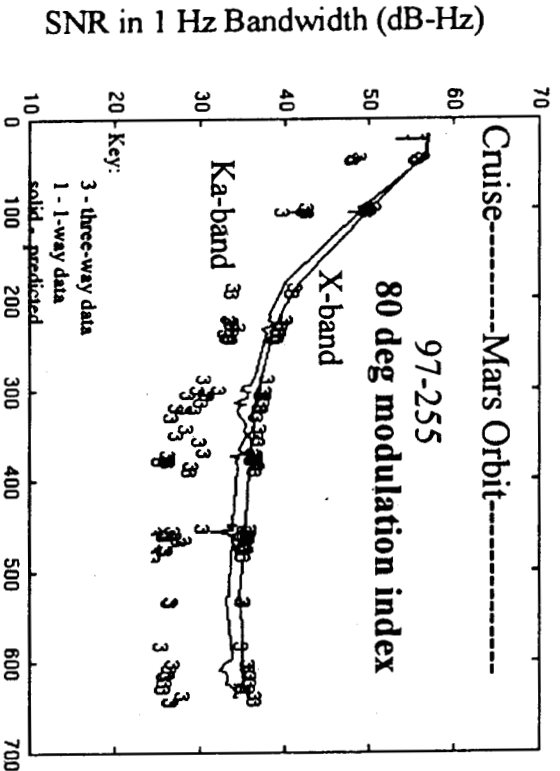
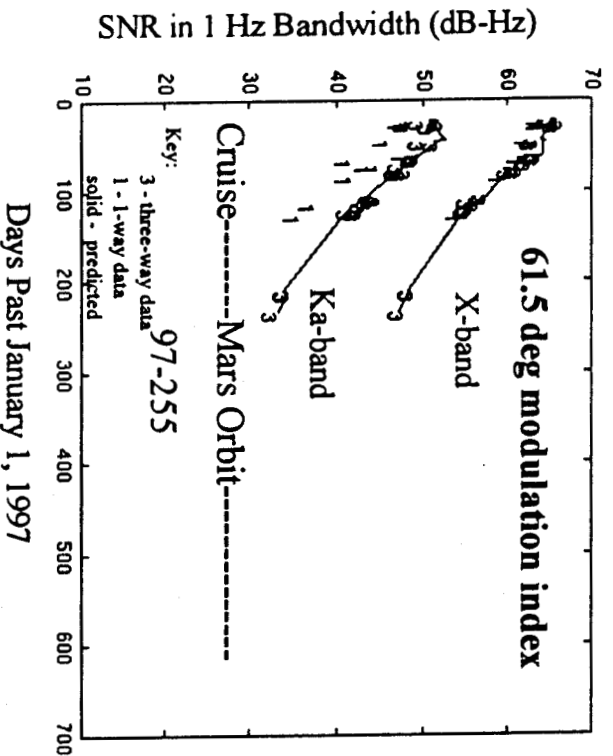
Ka-band System Noise Temperature for 97-212



Ka-band System Noise Temperature for 97-203



Single-Pass Pc/No



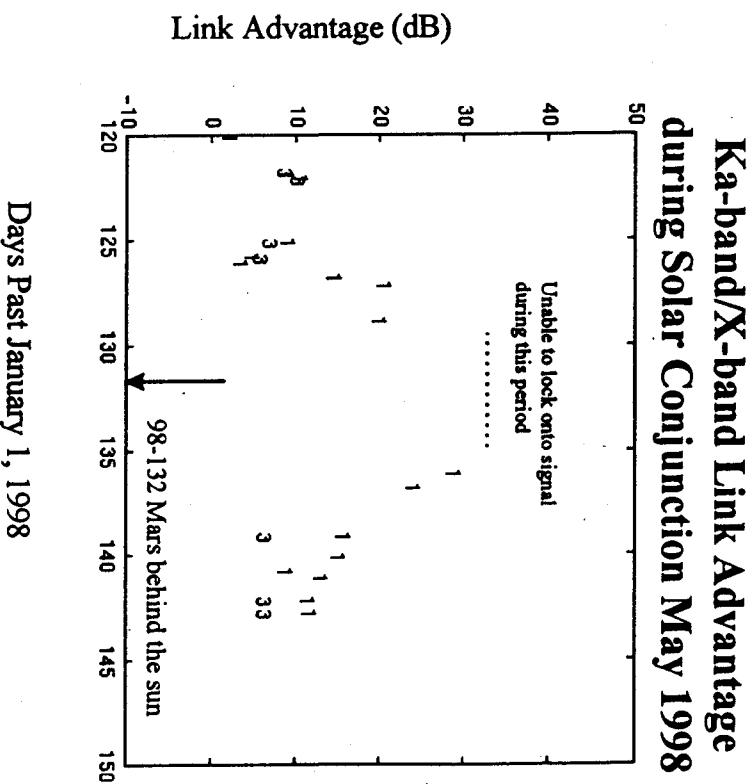
- 61.5 deg Modulation Index Pc/No
 - X-band 3-way Pc/No within 1 dB of predicted values
 - Ka-band 3-way Pc/No is 0.74 dB below predict (27 passes) - reasonable
 - Ka-band 1-way Pc/No is about 5.4dB below predict (11 passes)
 - attributed to reduced response of spacecraft equipment at the higher Ka-band 1-way frequency (32.008 GHz) versus 31.986 GHz 3-way frequency
- 80 deg Modulation Index Pc/No
 - X-band 3-way Pc/No agree to 0.1 dB of predicted values (67 passes)
 - Ka-band Pc/No are 7 dB below predict attributed to
 - higher subcarrier frequency (320 kHz)
 - higher modulation index
 - spurious frequencies
 - Higher scatter in measurements after Mars Orbit Insertion due to larger HGA pointing errors

MGS/KaBLE-II Link Advantage

- Measured Ka-band and X-band Pc/No values are differenced and adjusted to correct for preventable deficiencies at both bands
 - Assume equal spacecraft transmitted power, HGA efficiency and circuit loss
 - For projected future LNAs, Top over each pass adjusted accordingly
 - Backed out carrier suppression due to telemetry and ranging modulation
 - Additional correction applied to Ka-band signal strengths acquired with higher 320 KHz telemetry subcarrier frequency and (80 x 4) deg modulation index
 - Additional correction applied to one-way data.
- For cruise data acquired before 97-255 (HGA mispointing errors assumed to be minimal):
 - Average projected link advantage = 6.6 +/- 1.4 dB (55 passes)
- For data acquired after Mars Orbit Insertion, 97-255:
 - Projected link advantage degrades due to higher spacecraft pointing errors and/or possible equipment degradation since cruise

MGS/KaBLE-II Solar Corona May 1998

- Data were acquired during May 1998 Solar Conjunction Experiment when MGS was angularly near the sun
- Experiment demonstrated that Ka-band signal was more easily maintained than X-band signal
 - Ka-band signal is less affected by sun's corona.
 - Increased degradation of X-band signal due to
 - spectral broadening
 - angular broadening
- Significantly reduced X-band detection threshold
 - due to significantly higher X-band noise temperature due to solar corona and wider ground antenna beamwidth



MGS/KaBLE-II Frequency Data

- Analyzed frequency data where Ka-band frequency is coherent with X-band frequency
- Residuals for individual frequency bands dominated by
 - thermal noise
 - USO
 - Dynamic Spacecraft Motion
- Difference residuals ($f_x - f_{Ka}/3.8$)
 - All non-dispersive noise sources cancel (dynamic spacecraft motion, neutral atmosphere, frequency standards, etc.)
 - Remaining noise sources are thermal noise and charged particles
 - Thermal noise significant at short time intervals
 - Charged particles significant at high time intervals
 - Difference frequency is a measure of the charged particle effect on the X-band link
 - Allan deviations at 1000 sec decreases with increasing SEP angle
 - 1000-s Allan deviation of 6×10^{-15} is in agreement with predicted value in anti-solar direction

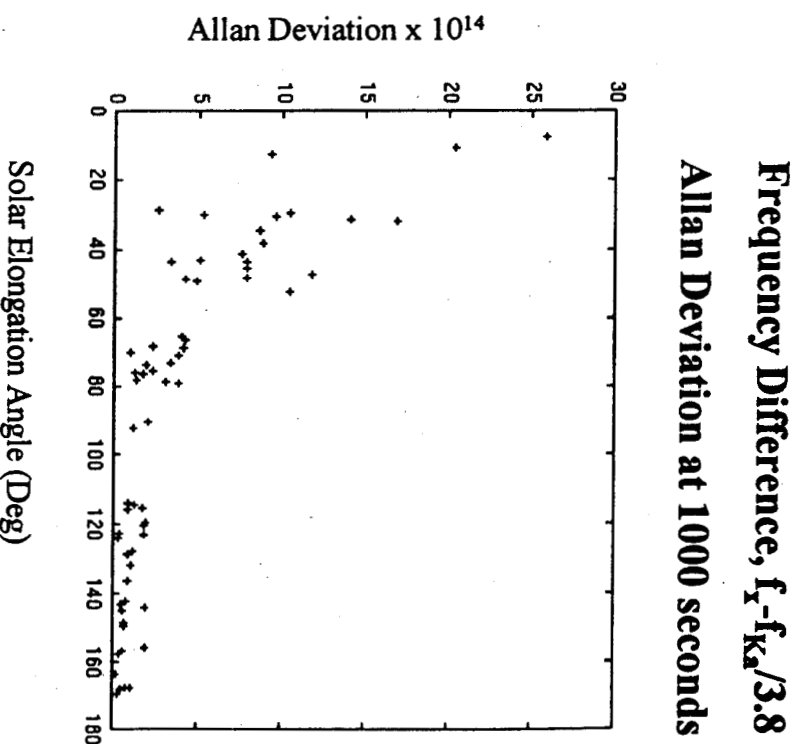


Figure 1

97-002 X Residuals vs. Time (SPM)

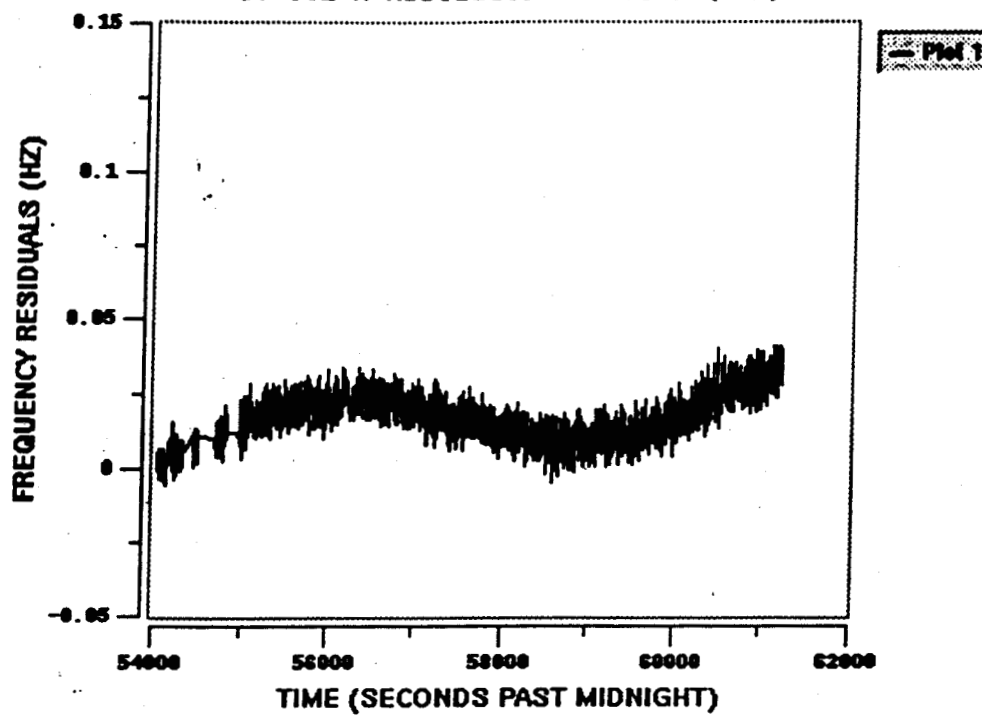


Figure 2

97-002 Ka Residuals vs. Time (SPM)

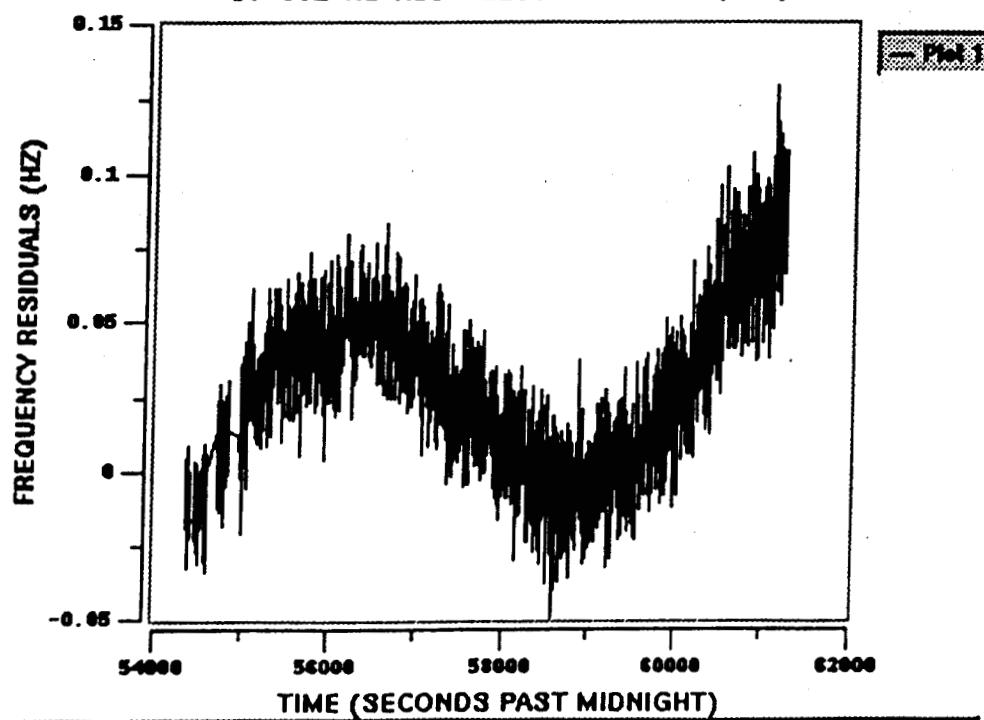


Figure 3

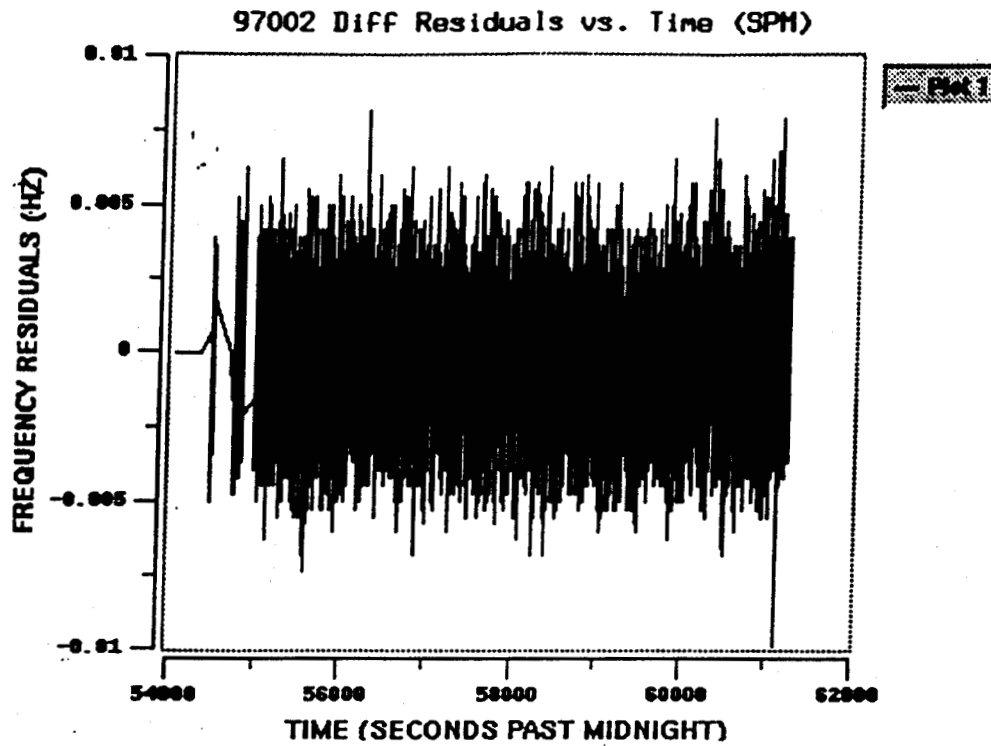
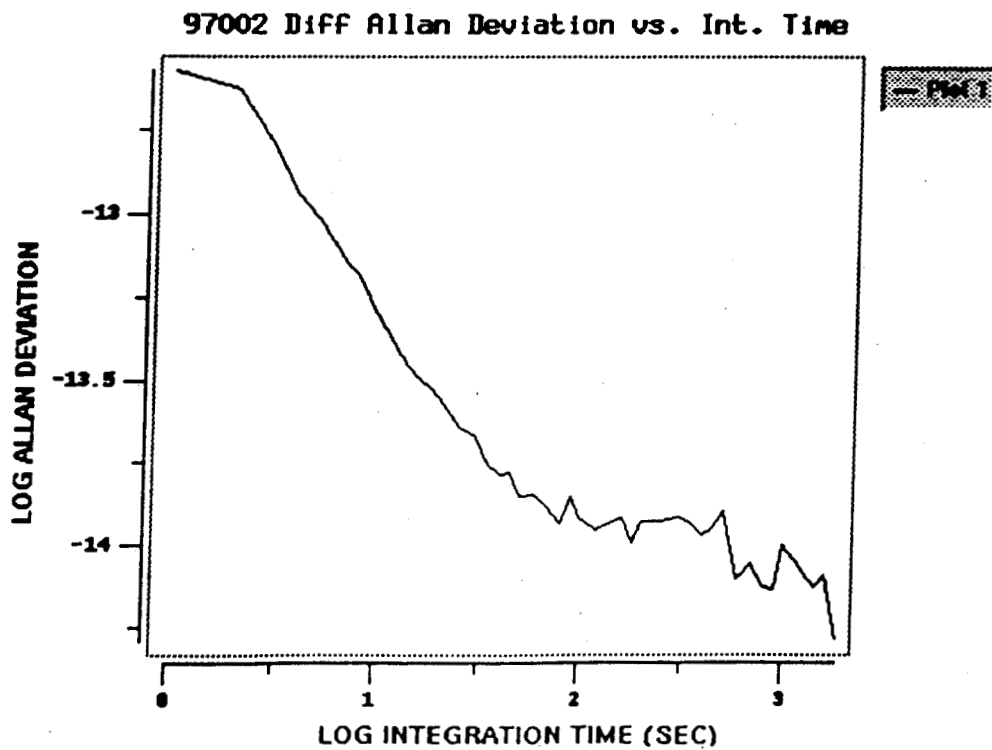


Figure 4



CONCLUSIONS

- MGS/KaBLE-II Link Experiment Measured Signal Strengths are in agreement with predicted values
- Frequency residual measurement statistics are consistent with expected noise sources
- These efforts will continue with MGS/KaBLE-II as well as future spacecraft such as DS-1 which will also provide X/Ka Link Data

Backup

MGS/KaBLE-II Link Advantage Pass 97-232, 60 Deg Mod Index Case

	X-band	Ka-band	Delta
Measured Pc/No	46.6 dB-Hz	32.2 dB-Hz	-14.4 dB
Power	25 W	1.2 W	13.2 dB
Antenna Gain	39 dBi	49 dBi	1.6 dB
Circuit Loss	1.0 dB	3.5 dB	2.5 dB
Net "EIRP" correction			17.3 dB
Ranging Suppression	0.2 dB	3.4 dB	3.2 dB
TLM Suppression	6.4 dB	7.0 dB	0.6 dB
LNA Temperature	3.3 dB (49K)	2.2 dB (82K)	-1.1 dB
NET ADVANTAGE			5.6 dB

Note - LNA Correction for X-band = $-10 \log[(T_{\text{top}} - 26)/T_{\text{top}}]$

Ka-band = $-10 \log [(T_{\text{top}} - 33)/T_{\text{top}}]$